Regional methods for estimation of design floods for small to medium sized drainage basins in Australia

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ABSTRACT In terms of overall economic value, design for small to medium sized rural basins is the most important aspect of flood estimation. Methods for these basins need to be based on observed flood data in the region, and should be simple to apply and familiar to designers, unambiguous in application, and of a probabilistic nature. As design sites are normally ungauged, regionalized procedures are required, but these methods must also recognize major differences in flood producing characteristics between different regions. Design methods to fulfil these requirements have been derived for most of Australia for inclusion in a revised edition of "Australian Rainfall and Runoff", the guide to flood estimation published by the Institution of Engineers Australia. The regional methods derived from observed data are of two general types, the probabilistic Rational Method and regional flood frequency procedures. Values of design parameters show much less variation with basin characteristics than for previously used methods based on judgement or plot experiments. The flood estimates are also of much greater accuracy.

INTRODUCTION

Development of regional procedures for the estimation of design floods on small to medium sized rural drainage basins is one of the oldest problems in hydrology. Despite the many methods developed and their wide use, in many cases there is serious doubt about their adequacy and accuracy. There is also considerable uncertainty and confusion regarding the principles involved and requirements of the methods. Even the terms "small" and "medium sized" are indefinite, and here will be applied to areas less than 25km$^2$ and up to 250 or 1000 km$^2$ respectively.

Regional flood estimation procedures for basins of these size ranges have recently been derived for regions covering most of Australia for inclusion in a completely revised edition of "Australian Rainfall and Runoff" published by the Institution of Engineers Australia (1987). The importance and development of this document are discussed later, and the design procedures adopted in it are described in more detail. General problems and requirements of design methods are considered first, and much of the discussion derives from the experience of the writer in leading the revision team and editing Australian Rainfall and Runoff.

IMPORTANCE OF REGIONAL METHODS FOR SMALL TO MEDIUM SIZED BASINS

A huge volume of research has been published in recent years on the estimation and modelling of floods. Despite this, relatively little attention has been paid to the development of improved design procedures for small rural basins, and there is a considerable gap between...
TABLE 1 Estimated average annual expenditure on works sized by design flood estimates for Australia as at 1988

<table>
<thead>
<tr>
<th>Class of works</th>
<th>Expenditure</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Aust. $ million</td>
<td></td>
</tr>
<tr>
<td>Rural roads - waterway crossings</td>
<td>240</td>
<td>35</td>
</tr>
<tr>
<td>Railways - waterway crossings</td>
<td>30</td>
<td>4</td>
</tr>
<tr>
<td>Farm dams</td>
<td>50</td>
<td>7</td>
</tr>
<tr>
<td>Dams and water supply schemes for small towns</td>
<td>50</td>
<td>7</td>
</tr>
<tr>
<td>Urban drainage</td>
<td>180</td>
<td>26</td>
</tr>
<tr>
<td>Flood mitigation and stream improvement works</td>
<td>30</td>
<td>4</td>
</tr>
<tr>
<td>Major dams</td>
<td>120</td>
<td>17</td>
</tr>
<tr>
<td>Total</td>
<td>$700</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 1 does not include the benefits or costs of flooding for which flood estimates are required for hazard mitigation and flood plain management studies. The table shows that over half the expenditure involves the types of flood estimation procedures that are the subject of this paper. In terms of national economics, these procedures are by far the most important aspect of flood estimation, and overall are of much greater importance than methods for estimating major floods on large drainage basins, for example for dam spillway design.

The importance of small basin design procedures is heightened by several other factors. They often provide a basis for design of urban drainage, which involves the second highest expenditure. This applies particularly to the Rational Method which is still very widely used in urban drainage design practice in most countries, despite the development of many computer models. The number of small basin designs relative to the total number of designs would far exceed the proportion of costs in Table 1, and the combination of small rural basin and urban drainage would probably exceed 90% of all flood estimates. Many estimates for small basins are carried out by designers with limited hydrological expertise. While this might not be desirable, it is a fact of life, and highlights the need for design methods for small basins to be as accurate and unambiguous as possible.

There are several reasons for the relative lack of attention that has been paid by researchers to the development of better design procedures for small and medium sized rural basins. It seems likely that there is a lack of appreciation by many researchers of the economic importance of small basin design, especially as individual structures on these basins involve relatively low expenditure, and design is generally carried out in a routine manner in minimum time. There is also a perception that methods are available in most cases for small basin design, thus reducing the incentive for development of
new methods. A further important factor is that development of
design procedures for these basins is not regarded by many involved
even in applied research as exciting or even intellectually or sci­
entically satisfying. It is also perceived as an activity that is
unlikely to increase prestige among research peers.

Despite this relative lack of attention to design methods for small
to medium sized rural basins, their importance as discussed above
demonstrates the need for development of the best possible methods
that will be accepted and used in practical design.

REQUIREMENTS OF DESIGN FLOOD PROCEDURES

Several requirements need to be met by a regional method of flood
estimation if it is to provide the best possible approach to design.
These requirements formed the basis of the principles adopted in the
development of procedures for Australian Rainfall and Runoff.

Procedures need to be based on observed flood data

A fundamental requirement is that design information and procedures
need to be rationally based on all of the available observed flood
data in the region. This is necessary so that application of the
procedures in design is likely to reproduce the statistical charac­
teristics of observed floods, which is the objective of design. Many
methods developed in the past and in widespread use at present are
primarily based on judgement and quasi-theoretical considerations, or
on the results of sprinkled plot or ring infiltrometer tests. While
this might have been acceptable in the past as the best available
approach, there is now sufficient observed streamflow data on small
to medium sized basins in most regions in many countries to provide
a much more satisfactory and valid basis, despite uncertainties in
high flow rating curves at many stations. It is therefore important
that wherever possible, design procedures should be rationally based
on observed flood data. This was adopted as the primary criterion
for selection of methods and design information to be included in
the revision of Australian Rainfall and Runoff.

Simplicity, lack of ambiguity and familiarity in application

Much of the flood estimation for small basins is carried out by
designers with little hydrological expertise, and little time is
generally available for design, as noted previously. Simplicity in
application and familiarity on the part of designers are important if
a new method is to gain widespread support. The Rational Method and
regional flood frequency procedures generally fulfil these requirements.

A second practical consideration is that many flood estimation
methods require subjective estimation of rather ill-defined variables,
often involving basin and vegetal cover characteristics. Different
designers can obtain widely different answers for a given design pro­
blem. Cordery & Pilgrim (1980) reported surveys of two groups, each
comprising about 40 engineers and senior technical support staff, who
were asked to estimate a particular design flood by the form of the
Rational Method that they used routinely. Estimates of time of con­
centration varied by up to five times, and the maximum estimate of
flood peak was over five times the minimum estimate. Over many years,
the writer has found similar variations in the application of
procedures of this type in assignments in graduate classes. Subjective differences of these magnitudes are entirely unsatisfactory. Design procedures need to be specified in a more definitive and unambiguous manner.

Probabilistic rather than deterministic interpretation

With methods in which a flood is estimated from a design rainfall, there are two quite different interpretations of the method applying to two different types of problems. In the first, the flood resulting from a particular storm is estimated, and the answer depends on the antecedent precipitation and the prevailing conditions on the basin. This is a deterministic problem and the method is used as a deterministic model.

The second type of problem is where a flood of a selected probability is estimated from a design rainfall of the same probability. The method is here used as a probabilistic model, and this is the interpretation that is almost always required and used in design.

Although the computational procedure may be virtually the same in both cases and the differences in the two types of problems are often not recognized, there are three important practical consequences of the differences in the interpretations. Firstly, a particular procedure may be good or satisfactory for one case, but quite unsuitable for the other. As discussed later the Rational Method using the probabilistic interpretation can be a very satisfactory approach for estimating design floods, but is not satisfactory for estimating the flood resulting from a given rainfall. Most of the criticism of the Rational Method has been based on a deterministic interpretation. The second consequence concerns the manner in which values of parameters are derived from observed data, the manner in which the values are applied and the manner in which the method is tested. Many design methods have been tested by their ability to reproduce particular observed events. This is inappropriate, as illustrated by Hoesein et al. (1989) with the US Soil Conservation Service Method. Thirdly, the interpretation of a method affects the manner in which its parameters are viewed by designers and analysts. For example, the common visualization of the runoff coefficient as the fraction of rainfall that runs off is correct in the very unusual case where the Rational Method is used to estimate an actual flood, but is quite incorrect in the design case, as discussed later.

It is important that flood estimation methods should be developed on a probabilistic basis if they are to be used to estimate design events. This principle is illustrated in a later section with the Rational Method as incorporated in Australian Rainfall and Runoff.

Recognition of regional differences

While the objective of a design procedure for small to medium sized ungauged basins is that it should be applicable over a large region, there are considerable differences between the hydrological characteristics of different regions. These probably result from differences in the types of runoff processes that occur in the climatological conditions, and in the types and structure of soils and their infiltration characteristics. In many cases the physical reasons are not fully understood, but the empirical evidence indicates that different design information, and even methods, may be necessary for different regions.
Three examples of regional differences in flood characteristics in Australia are outlined below (see Fig. 1). In arid western New South Wales, any rainfall greater than 16 mm in total, or 5 mm in 1 h, is very likely to produce runoff (Cordery et al., 1983), whereas after a dry period in the humid east of the State, up to 120 mm of rain, regardless of the intensity, may be required to produce appreciable runoff (Pilgrim, 1966). Large differences in runoff coefficients derived from observed data were reported by Pilgrim (1982) for different regions of Australia. In many cases the relative values were quite different to what might be expected from climatological and basin characteristics. The third and most spectacular example is provided by two formulae for time of concentration derived from minimum times of rise of observed hydrographs. For 96 basins in eastern New South Wales, McDermott & Pilgrim (1982) and Pilgrim & McDermott (1982) derived the formula:

\[ t_c = 0.76 A^{0.38} \]  

where \( t_c \) is in hours and \( A \) is area in km\(^2\). Flavell (1983) independently derived a formula of the same form from observed times of hydrograph rise on basins in the south west of Western Australia:

\[ t_c = 2.31 A^{0.54} \]  

Although (1) and (2) have the same form, the ratios of the values they give range from 2.1 to 7.4 for a range of basin sizes of 0.1 to 250 km\(^2\), reflecting different runoff processes in the two regions.

These three examples illustrate the fact that with the present state of knowledge, it is not possible for a single procedure to be applicable to the whole of a country of the size of Australia with its diversity of hydrological characteristics. Different regional design information, and even possibly methods, are required for different regions if the statistical characteristics of observed floods are to be reproduced.

AUSTRALIAN RAINFALL AND RUNOFF

The 1987 revision

Australian Rainfall and Runoff (AR & R) is the guide to flood estimation for Australia, and is published by the Institution of Engineers Australia (1987). It covers all aspects of flood estimation from urban drainage to extreme floods on large rural basins for the whole 8 million km\(^2\) of the country. While the document is not intended to be entirely prescriptive or a strict code of practice, it is regarded as authoritative by all involved professionally with flood estimation and by the courts.

Two previous editions were published in 1958 and 1977. The present revision took five years to complete, and was mainly carried out by a team from the University of New South Wales. The preparation of the design rainfall information in the document involved a major project by the Australian Bureau of Meteorology. The entire revision was carried out under the general supervision of the National Committee on Hydrology and Water Resources of the Institution of Engineers. Considerable effort was expended to obtain the maximum input from and interaction with the profession to ensure that the best possible information was included, and that the final document would be accepted by the
profession. A representative advisory panel throughout the project and a comprehensive initial questionnaire provided guidance for the revision team. Workshops were conducted around Australia to discuss proposed procedures and to obtain local information, and close liaison was maintained with other professional bodies. Several papers were published describing proposed procedures, a draft of the final document was distributed to 50 reviewers, and several procedures were released to practitioners on a trial basis for testing.

A feature of the revision was that it provided a catalyst for the analysis of data and development of design information by a large number of designers and organizations around Australia. Considerable effort was expended in encouraging this work, and the result was that regionalized design methods were developed for regions covering most of Australia. The response of the various State and regional authorities reflects the perceived need of these authorities for accurate flood estimation methods for small and medium sized rural basins based on observed data. AR & R has proved to be an excellent means of achieving technology transfer in flood estimation.

Principles adopted

The main principles adopted in preparing the document were:
(a) Firm guidance was given to designers, while falling short of prescribing a code of practice.
(b) A discussion of the fundamental principles underlying each method was included, as well as the actual description of the method, in the belief that good design not only requires the use of a good method, but also an understanding of the principles underlying the method and its limitations.
(c) Different design information and methods were given for different regions, as discussed earlier.
(d) The primary criterion for the selection and inclusion of a method was that it should have been derived rationally from observed flood data, as discussed earlier.
(e) Considerable stress was given to the difference between a deterministic method for reproducing a flood resulting from a given storm, and a probabilistic design method.
(f) Explicit recognition was given to the fact that flood design is carried out on the basis of a selected risk.
(g) Specific and quantitative guidance was included on the choice of the best method of flood estimation for different circumstances.

Types of methods

The small to medium sized rural basins for which design floods are required are usually ungauged so that regional methods are required. The methods developed from observed data and included in AR & R are of two general types. These are the probabilistic Rational Method and regional flood frequency procedures. They are described later in more detail. The choice of method was made by the authority or researcher who analyzed the regional data and developed the method.

Runoff routing methods with regional relations for evaluating parameters were available for most regions. These models involve the routing of rainfall excess through a model of basin storage, generally by means of a computer (Pilgrim et al., 1982). For some regions, synthetic unit hydrograph procedures were also available. These two
more sophisticated methods were also recommended in AR & R as alternatives to the Rational and regional flood frequency methods for designs where the additional time required is available and the extra effort involved is justified. This would rarely be the case in practice, and as discussed later, the results would not necessarily be more accurate.

Arbitrary methods, such as the Rational Method with handbook-type parameter values based mainly on judgement and the US Soil Conservation Service method, are only recommended for two regions where a procedure has not been derived from observed data.

Recommended Methods

The regions for which the probabilistic Rational Method and regional flood frequency methods have been derived and recommended in AR & R are shown in Fig. 1. To a large extent, the regions follow State boundaries. This is not for hydrological reasons, but is a result of gauging operations coming under State jurisdiction, and in most cases the analysis of data and development of methods have been carried out by State authorities. Methods derived from observed data were not available for Queensland and eastern Tasmania.

The inland of Australia and most of Western Australia are arid or semiarid, with sparse habitation and few roads. Records are available from relatively few gauging stations, and methods for these regions are necessarily of lower accuracy than those for the humid south east of the country and the south west corner.

THE PROBABILISTIC RATIONAL METHOD

As used in design, the Rational Method formula is:

![Fig. 1 Regions for which design methods in Australian Rainfall and Runoff have been derived from observed data.](image-url)
\[ Q(Y) = 0.278 \ C(Y) \cdot I(t_c, Y) \cdot A \]  

(3)

where the peak discharge \( Q \), average rainfall intensity \( I \) and area \( A \) have units of \( \text{m}^3\text{s}^{-1}, \text{mm} \cdot \text{h}^{-1} \) and \( \text{km}^2 \) respectively. The rainfall has a duration of \( t_c \), and \( C \), as well as \( Q \) and \( I \), has an average recurrence interval (ARI) of \( Y \) years. The intention in design is that the formula converts a rainfall with ARI of \( Y \) years derived from the design intensity-frequency-duration data for the region into a peak discharge with the same ARI. It is also the intention that this is the value that would be given for the ARI by a frequency analysis of observed floods if a long and representative record of discharge was available at the site. Both the design rainfall and peak discharge are probabilistic values derived from frequency analyses, and the design formula in (3) really has nothing to do with the runoff in a particular storm.

To derive design values of \( C \), equation (3) is rearranged as:

\[ C(Y) = \frac{Q(Y)}{I(t_c, Y) \cdot 0.278A} \]  

(4)

Fig. 2 illustrates the derivation of the value of \( C(Y) \) for a particular ARI of \( Y \) years for a gauged basin. The figure shows frequency curves of recorded floods and of design rainfalls of duration \( t_c \). The rainfall would be from the design intensity-frequency-duration data for the site. With the appropriate scaling of \((0.278A)\), the value of \( C(Y) \) is given by the ratio of \( Q(Y) \) to \( I(Y) \). The value of \( C(Y) \) will be different for different values of \( Y \). In all of the Australian studies, \( C(Y) \) has varied with ARI in a consistent and predictable manner that could be incorporated into the design procedure for each region. \( C(Y) \) derived in this manner exactly fits the way in which the runoff coefficient is used in design in transforming the \( Y \) year design rainfall into an estimate of the \( Y \) year flood.

Viewed in this way, the probabilistic Rational Method is conceptually a type of regional flood frequency procedure, with rainfall intensity as one of the independent predictor variables. As rainfall intensity is one of the major determinants of the flood characteristics of a basin, this approach is an efficient form of regional flood frequency analysis, and is simple and familiar to most designers.

With this probabilistic interpretation, time of concentration as a physical measure of maximum travel time is not really relevant. However, (4) shows that \( C(Y) \) depends on the duration of rainfall, and some design duration related to basin characteristics must be speci-
Regional methods for estimation of design floods

fied. A typical response time is appropriate, and $t_c$ is a convenient measure. In this context, its accuracy regarding travel time is much less important than the consistency and reproducibility of derived $C(Y)$ values. Also, values of $C(Y)$ cannot be compared unless consistent estimates of $t_c$ are used in their derivation.

The probabilistic interpretation of the Rational Method was developed by Horner & Flynt (1936), but was then neglected until the work of Schaake et al. (1967) with urban drainage basins and French (1967) with rural basins. The latter was extended by French et al. (1974), and the first complete design procedure for Australia was developed by McDermott & Pilgrim (1982) and Pilgrim & McDermott (1982) for eastern New South Wales, covering an area of approximately 1000 by 400 km. As noted earlier, equation (1) for $t_c$ was derived from minimum times of rise on 96 basins. Runoff coefficients were derived for a range of ARIs from observed floods on 308 basins. Possible relationships between $C(10)$ and basin characteristics were investigated, but the most satisfactory procedure was found to be the mapping of $C(10)$ values, and drawing contours or isolines. In this, consideration was given to the shape of isohyets of average annual precipitation and short duration design rainfall intensities, topography, soil type, and relative reliability of gauging station records. Comparison of the deviations between the derived values and values estimated from the contours with the expected errors in the flood frequency curves indicated that the mapped contours extracted virtually all of the available information from the frequency analyses of recorded floods. Real improvements in accuracy would require longer or more accurate records, or greater density of stations. When the new design rainfall data were developed for the 1987 AR & R, the $C(10)$ values had to be re-derived and the contours redrawn, as (4) shows that values of $C$ depend on the design rainfalls that are used. Fig. 3 shows the redrawn $C(10)$ contours for part of south eastern New South Wales.

Average frequency factors were also derived for basins above and below 500 m elevation for each of six regions within eastern New South Wales. These enable $C(Y)$ values to be determined from $C(10)$ for a range of $Y$ from 1 to 100 years.

Derivation of the Rational Method procedure for the other regions shown on Fig. 1 closely followed the procedure of McDermott & Pilgrim.
(1982) and Pilgrim & McDermott (1982). C(10) values were mapped for Victoria with State-wide frequency factors, and C(Y) values were adopted as applying to the whole region for each of South Australia and the Northern Territory. For 11 of the regions in Western Australia, regressions were developed between C(10) and basin characteristics, while C(2) was used in two regions. The basin variables of area, stream length, percentage clearing and elevation difference from stream source to outlet were significant in different relationships. In eight regions, only one of these variables was involved, and in the other five, only two were involved. For each region, frequency factors were derived for determining C for other ARIs.

In the application of the procedures for all regions, use of the maps of C(10), regressions and frequency factors allows unambiguous determination of the design flood estimates. The wide variations that occur in some methods in values assigned to vague and ill-defined basin characteristics are avoided in these procedures. In almost all cases, different designers should obtain the same answers in a given design situation.

REGIONAL FLOOD FREQUENCY PROCEDURES

These methods for the regions shown on Fig. 1 followed standard procedures, and were of three types. The first type involved a dimensionless flood frequency curve for the region with actual discharges divided by a reference discharge for each basin. A regression relates the reference discharges to basin characteristics. This approach is of the same type as the Index Flood Method (Dalrymple, 1950, 1960). The second type is a variation of this, with the dimensionless frequency curve replaced by frequency factors. The third type consists of separate multiple regressions for each ARI, following the approach of the US Geological Survey (1967).

The method of the second type derived by McDermott & Pilgrim (1983) for arid western New South Wales involved an innovative feature. Only one group of gauged basins was available in the region. In the absence of other observed data, field estimates of bankfull flow were utilized as reference discharges for 68 basins. From the group of gauged basins and other information in surrounding regions, the bankfull flows were estimated to have an ARI of 2.5 years, and frequency factors were determined for other ARIs. While the accuracy would be lower than for methods based on frequency analysis of observed floods, the approach provides at least an approximate method for a region with very little data, and its accuracy would be better than estimates from design values based on judgement.

DISCUSSION OF THE DERIVED PROCEDURES

Accuracy

As noted in the description of the probabilistic Rational Method, the mapped contours of C(10) for eastern New South Wales were shown to extract virtually all of the available information from the flood frequency curves. A similar investigation was not carried out on the procedures derived for other regions, but it seems likely that similar conclusions would be reached. Further improvements in terms of the accuracy of practical flood estimates will require longer records and/or more gauged basins.
As the new methods are derived from observed flood data, they would almost by definition be more accurate than the previous methods with design values based mainly on judgement. This was demonstrated with the Rational Method for eastern New South Wales by testing it on 271 of the basins used in derivation. Some bias would have been introduced by the use of the same basins in testing as in deriving the method, but as the method depends on the use of all available data, split sample testing is not feasible, and only small bias would be likely. Taking the 10 year ARI discharges from the flood frequency curves as the correct values, 65% of the estimated 10 year discharges were within ±15% of the correct values, and only 3% and 1% respectively over and underestimated the correct values by greater than 50%. Corresponding percentages given by the Rational Method in the previous 1977 edition of AR & R, which was not based on observed data, were 14% within ±15%, and 37% and 16% over and underestimated by greater than 50%. The dramatic increase in accuracy was also demonstrated in economic terms by a study of costs that indicated that use of the new method for design would lead to average savings of about 30% of the total costs for flood-passing structures on small to medium sized basins in eastern New South Wales (McDermott & Pilgrim, 1982).

In some regions, notably Western Australia, design data derived from observed floods are available for both the probabilistic Rational Method and a regional flood frequency method. Although statistical measures of the accuracy of fitting the observed data are similar for both methods, the Rational Method is generally to be preferred, because the structural forms of the relations in this method are more logical physically, and rainfall intensity is directly incorporated.

As noted earlier, more sophisticated methods such as runoff routing models or synthetic unit hydrographs could be used for small basin design if the additional time and effort can be justified. However for ungauged basins, regional relationships for design parameters are required. These are usually derived from a much smaller data base than that used in the probabilistic Rational Method or regional flood frequency methods. For example in eastern New South Wales and Victoria, the Rational Method is based on data from 308 and 385 basins respectively, whereas the parameter relations for the most commonly used runoff routing model are based on data from 29 basins in eastern New South Wales, and 21 and 19 basins in two regions in Victoria. With the much larger data bases, it is likely that the simpler methods would be more accurate than the sophisticated methods in many regions.

Effects of basin characteristics

Basin characteristics such as soil type, cover and slope are assumed to have a large effect on the values of design parameters in most of the flood estimation methods that are not based on observed flood data, such as handbook versions of the Rational Method and the US Soil Conservation Service Method. A feature of the design methods derived from frequency analysis of floods of similar magnitude to those of interest in design is that design parameters, such as runoff coefficients, are much less variable than handbook values. Variations in most basin characteristics were found to have little effect on design variables and therefore on the estimated flood peaks. For example, time of concentration was related only to basin size for all regions where it could be derived from observed data. In eastern New South
Wales and Victoria, location was the only variable that affected $C(10)$, which generally decreased with distance from the coast. This probably reflects reduction of average annual rainfall away from the coast with consequent reduction in the average antecedent wetness and hence flood potential of basins. As noted earlier, only one basin characteristic was significant in the design relations for $C$ in eight regions in Western Australia, and only two in the other five regions. This lack of variation of design values with basin characteristics corresponds with the lack of dependence of losses in major floods on soil and cover characteristics reported by Cordery & Pilgrim (1983), and with the runoff curve numbers for the US SCS method derived by Hoesein et al. (1989).

A further feature of the derived runoff coefficients was their stability with basin size up to at least 250 km$^2$. This contrasts with the expected "theoretical" decrease of $C$ as area increases, and the arbitrary limit of basin size normally imposed. The data indicated that the runoff coefficient values might remain stable to areas much greater than 250 km$^2$. Apparently the attenuating effect of basin storage as size increases is balanced by reduced design rainfall intensity, allowing the runoff coefficient to remain almost constant.

CONCLUSION

The three editions of Australian Rainfall and Runoff to date have proved to be an excellent means of information transfer to designers, not only for flood design for small to medium sized basins, but for all aspects of flood estimation. Publication by the Institution of Engineers Australia has ensured that the best available information has been included, and that the recommended methods are adopted in practice.

In terms of overall economic value, design for small to medium sized rural basins is the most important aspect of flood estimation. It is therefore important that the best possible methods should be developed from observed flood data for design on these basins. As design sites on these basins are normally ungauged, regionalized design methods are required. The probabilistic Rational Method and regional flood frequency procedures that have been derived for different regions in Australia and included in the 1987 AR & R satisfactorily fulfil the requirements for design methods for these small to medium sized basins. The derived values of design parameters show much less variation with basin characteristics than previous handbook type methods based largely on judgement and infiltrometer experiments, and the resulting estimates of design floods are of much higher accuracy.

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